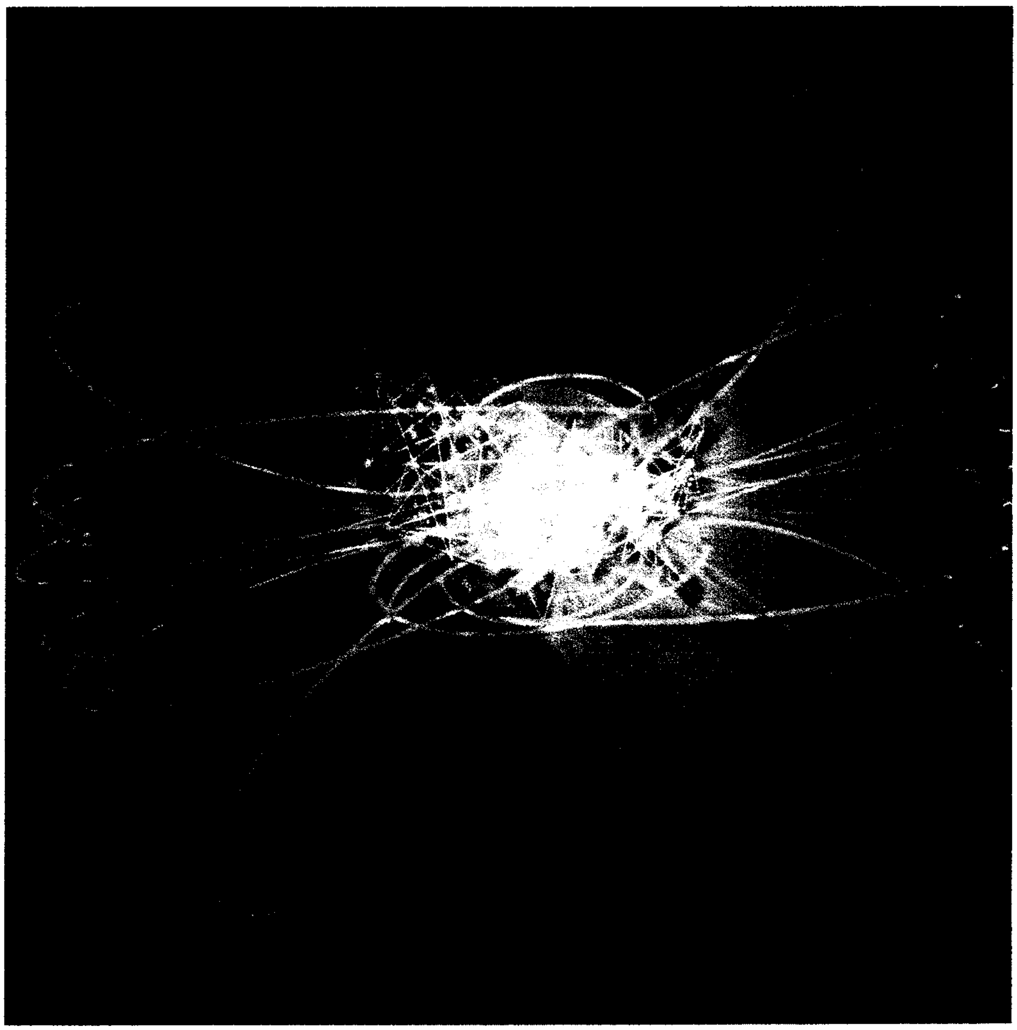
U.S. Department of Transportation

EFFECTIVE GLOBAL TRANSPORTATION IN THE TWENTY-FIRST CENTURY: A VISION DOCUMENT

SEPTEMBER 1999



PREPARED BY

"ONE DOT" WORKING GROUP ON ENABLING RESEARCH
RESEARCH AND TECHNOLOGY COORDINATING COUNCIL

Effective Global Transportation in the Twenty-First Century: A Vision Document

September 1999

Prepared by
"ONE DOT" Working Group on Enabling Research
Research and Technology Coordinating Council
U.S. Department of Transportation

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND TECHNOLOGY COORDINATING COUNCIL
"ONE DOT" WORKING GROUP ON ENABLING RESEARCH

Chair

Norman Paulhus	Research and Special Programs Administration

Members

Richard Biter	Deputy Director, Office of Intermodalism
Randy Stevens	Federal Aviation Administration
Paula Ewen	Federal Highway Administration
John Punwani	Federal Railroad Administration
K.T. Thirumalai	Research and Special Programs Administration
Peter Manning	Volpe National Transportation Systems Center, Research and Special Programs Administration
John Hopkins	Volpe National Transportation Systems Center, Research and Special Programs Administration

"ONE DOT" Facilitators

Jerome Davis	Maritime Administration
David Sargent	Research and Special Programs Administration

U.S. DEPARTMENT OF TRANSPORTATION RESEARCH AND TECHNOLOGY COORDINATING COUNCIL

Chair:

Fenton Carey	Associate Administrator for Research, Technology and Analysis, Research and Special Programs Administration

Members:

Eva Williams	Office of Budget and Program Performance
Joseph F. Canny	Deputy Assistant Secretary for Transportation Policy
Richard Biter	Deputy Director, Office of Intermodalism
Will Terry Moore	Office of Small and Disadvantaged Business Utilization
John Daly	Office of Intelligence and Security
David J. Litman	Director, Office of Acquisition and Grant Management
Michael Grimes	Chief, Office of Research and Development, United States Coast Guard
Herman A. Rediess	Director, Office of Aviation Research, Federal Aviation Administration
Patricia Grace Smith	Associate Administrator for Commercial Space Transportation, Federal Aviation Administration
Dennis C. Judycki	Director, Research, Development and Technology, Federal Highway Administration
Christine M. Johnson	Program Manager, Operations, Federal Highway Administration
James T. McQueen	Associate Administrator for Railroad Development, Federal Railroad Administration
Raymond R. Owings	Associate Administrator for Research and Development, National Highway Traffic Safety Administration
Edward L. Thomas	Associate Administrator for Research, Demonstration and Innovation, Federal Transit Administration
Alexander C. Landsburg	Coordinator of Research and Development, Maritime Administration
David Mednick	Bureau of Transportation Statistics

Consultant:

Richard R. John	Director, Volpe National Transportation Systems Center

EFFECTIVE GLOBAL TRANSPORTATION IN THE TWENTY-FIRST CENTURY: A VISION DOCUMENT

BACKGROUND

This vision document is intended to summarize what a future transportation system might look like in the period around 2020, and provide some general indications about where transportation possibly may be headed in the 10-20 years thereafter. It is based on optimistic assumptions about (1) availability of Federal funding for transportation research, technology development, and implementation, (2) success in the conduct of enabling research, and (3) effective public-private partnership arrangements to help deploy new technology. This document does not assume, for the most part, significant breakthroughs in energy production technologies. It is not intended to be a specific technology forecast, but to provide a vision of the types of transportation services which might be useful in that time period, based on trends we see today, and some of the most promising technological opportunities for delivering new or needed services. In the process, it will set forth some possible enabling research activities which could lead to the kinds of needed systems.

This vision for the nation's transportation system is based on an environmental scan and trend analysis, originally undertaken to support development of the U.S. Department of Transportation's ***Strategic Plan***[1] and the ***NSTC Transportation Science and Technology Strategy***.[2] This assessment took into account the elements of today's transportation system; socio-economic and demographic forces shaping transportation demand and supply; and, the likely roles, responsibilities, and resources of the government and its transportation stakeholders. This trend analysis provided the basis to anticipate future transportation needs and technology-based solutions.

Because of the time required to deploy or upgrade major infrastructure improvements, the transportation enterprise has considerable inertia: long lead times are required to plan, develop and effect systemic changes. Many of the capabilities described in this document may require time to achieve widespread deployment.

The vision and goals for Federal transportation programs are articulated in the Department's ***Strategic Plan***, and other transportation-related documents like the NSTC ***Transportation Science and Technology Strategy***, and its implementation documents, the ***NSTC Transportation Technology***

---

[1] See especially Appendix B, *"Transportation Trends;"* in the ***U.S. Department of Transportation Strategic Plan 1997-2002***; September 30, 1997.

[2] National Science and Technology Council; ***Transportation Science and Technology Strategy;*** Washington, D.C.; September 1997.

Plan[3] and ***NSTC Transportation Strategic Research Plan.*** [4] Together with the key socio-economic and environmental trends and goals summarized below, these plans will drive forward-looking transportation policies and programs for the 21st century.

Questions may be raised about the time period in which specific technologies mature. Appendix A summarizes a technology forecast conducted by The George Washington University which highlights the specific time frames in which advanced technologies will become available.[5]

When dealing with long-term visions, it is especially important to avoid being constrained by current technologies and contemporary thinking. For example, in 1863 Jules Verne wrote the novel ***Paris in the Twentieth Century.*** Set in 1960, the novel forecast such modern inventions as automobiles, automated urban rail systems, electric lights, computers, calculators, fax machines, and electrified musical instruments. His publisher, Pierre-Jules Hetzel, flatly rejected the work, observing that, "No one today will believe your prophecy." In 1989, Verne's manuscript was re-discovered, and published as a "lost novel," selling two hundred thousand copies in its first year in print. The ultimate validation of Verne's "unbelievable" vision underlines the importance of keeping a long-term perspective in making long term forecasts.[6]

THE ONGOING SUBTLE REVOLUTION

A technology revolution is now quietly and thoroughly transforming the nation's transportation system from the inside out: Vehicles and guideways look much as they have, but inside changes have been occurring rapidly. In personal vehicles, microchips regulate engines; new technologies control car and truck braking; and electronic tuning ensures cleaner engine burn. Vehicle components, materials, and systems are safer than a decade before, and are still improving. Flame-retardant materials have replaced flammable padding in cars, buses, trains, and airplanes, and plastics have replaced other structural materials. Highway and airport pavements are more durable, cheaper, and easier to maintain. Communication, information, and navigation systems integrated into passenger cars are enabling smarter and safer personal driving. Aircraft continue to become quieter, more efficient and environmentally friendly, and electronic applications and tracking systems have revolutionized the freight industry. And, despite the increasing level of technical sophistication, the costs of many transportation system components -- particularly those linked to electronics -- are coming down.

---

[3] National Science and Technology Council; ***Transportation Technology Plan;*** Washington D.C.; November 1998.

[4] National Science and Technology Council; ***Transportation Strategic Research Plan;*** Washington, D.C.; May 1999.

[5] Halal, William; Kull, Michael; and Leffman, Ann; "Emerging Technologies: What's Ahead for 2001-2030;" in ***The Futurist;*** November-December 1997.

[6] Verne, Jules; ***Paris in the Twentieth Century***; Random House; ISBN 0-679-44434-3; Translation copyrighted 1996.

Enabling Technologies for Transportation

The continued development and maturation of several groups of technologies could together dramatically transform transportation as we know it over the next several years, especially in a nation with a robust economy. These technologies will enable the United States to build a transportation system that can provide better, more efficient and environmentally friendly service adapted to individual needs and preferences of all its users, at an affordable cost. They include the following:

- Improved understanding of **human performance and behavior**, which has highlighted the critical role fatigue plays in many crashes and incidents. It has led to the development of techniques to identify performance degradation and countermeasures which can improve vehicle operator alertness. A better understanding of the ways people interact with automated systems and information displays is leading to system control and operations improvements. Work on human performance also makes possible transportation design changes to reduce the likelihood of operator error, and enhance system safety and efficiency.

- **New computer, information and communications systems**, which have already transformed the way the transportation system is planned, designed, developed, maintained, managed and controlled. Computers regulate and monitor gas and oil pipeline flows and safety. On the highways, video-monitored intersections and synchronized traffic lights are already improving safety, capacity, and efficiency of urban and corridor travel. Positive Train Control systems have a similar potential to improve railroad safety and efficiency. Users with computer terminals already can conduct instant travel planning, reservations, ticketing, and rerouting through Internet connections for many kinds of trips and travel. Electronic tagging technology is used for diverse applications such as automated toll collection on turnpikes and the automatic identification of freight train consists. Fiber optic networks have proliferated, and may accelerate developments in the fast-growing field of photonics, which seeks to create computers and other machines that use light (photons) rather than electric current to transmit and process information.

- **Advanced material and structural technologies**, which have led to new, environmentally benign, and corrosion resistant materials (like geosynthetics and fiber-reinforced composites) used in crash-resistant vehicles and improved guideways. Other physical infrastructure improvements include durable recycled pavements; and composite wrapping materials to reinforce older structures. New kinds of superconducting and magnetic materials may make high speed ground transportation more attractive, and improved high-temperature alloys will lead to supersonic, hypersonic and orbital craft.

- **Energy, propulsion and environmental engineering advances**, which provide options to deliver improved transportation service that is cheaper, more energy efficient, and environmentally friendly. A variety of new powerplants for personal vehicles which have entered operation on a test basis, including fuel cells, advanced batteries and alternative-fueled engines, will have particularly broad impacts. The use of alternative fuels like natural gas can reduce emissions of nitrogen oxides, energy costs, powerplant maintenance costs, and transfer payments overseas. New turbine-powered locomotives now under development are expected to accelerate implementation of high-speed rail corridor services throughout the country. New technology turbojet/ turbofan, ramjet and supersonic combustion ramjet, and linear aerospike engines may transform aviation during the same period.

- **Sensing and measurement technologies,** which are making transportation safer and more reliable by detecting obstacles to moving vehicles, weather patterns, changes in development resulting from transportation, and emissions of greenhouse gases and other system products. Non-destructive evaluation (NDE) techniques using advanced sensor approaches will become more important as the physical infrastructure of the transportation system grows older, and has to be replaced.

- **Analysis, modeling, design and construction tools,** which will enable system planners to experiment with alternative system configurations, predict the performance of those systems, assess the impacts of those systems, and develop design improvements in one integrated process. A new generation of decision support models will improve targeting of transportation investments. Structural and crash performance "testing" may be done at lower cost with simulation models.

In some cases two or more trends re-enforce each other. For example, the emergence of "smart structures" and evolution of "intelligent materials" with built-in sensors (eventually of sub-microscopic size) will improve safety, and reduce the possibility of sudden failures. High temperature alloys, new propulsion concepts, and upgraded air traffic control may make feasible new kinds of airliners, which fly higher and faster than the current generation of planes. Likewise, many advances in computers, information technology, telecommunications, navigation, materials, structures, propulsion, sensing and human factors have been occasioned or accelerated by space transportation applications.

In addition, our present $300 billion telecommunication industry is becoming inextricably linked with the transportation system. Transportation moves people and physical objects, while communications moves data and ideas. The two systems link and network billions of users across the globe constantly. Again, the two reinforce each other's growth. GPS-aided in-car navigation and other satellite-based services to serve multi-modal transportation users become possible with real-time communication links to the satellites. Geographic information systems (GIS) will utilize real-time data from satellite positioning systems and other kinds of remote sensors, and will be a major resource for planners of future transportation systems to draw on. As these systems and improvements come on-line, they set the standards of performance for future systems to match and exceed.

The Small Frontier – Nanotechnology

In the longer term, advances in nanotechnology, which involves working with substances at the atomic or molecular level, will impact all of these technology areas. The size scales being considered in nanotechnology are much smaller than ever dealt with in manufacturing or engineering: for example, a human hair is about 10,000 nanometers thick.

Rice University characterizes nanotechnology in three distinct, but highly interdependent, areas:

1. "Wet" nanotechnology, which is the study of biological systems that exist primarily in a water environment.
2. "Dry" nanotechnology, which derives from surface science and physical chemistry, focuses on fabrication of structures from carbon, silicon, and other inorganic materials.
3. Computational nanotechnology, which permits the modeling and simulation of complex nanometer-scale structures.[7]

Nanotechnology will provide a variety of tools to build the transportation system for the twenty-first century. For example, advances in nanotechnology may make possible carbon-based fibers which are 100 times stronger than steel, at only one-sixth the weight.[8] Among the breakthrough applications that might be forthcoming in transportation from nanotechnology applications are the following:[9]

- Nanotechnology will yield advanced materials that will allow for longer service life and lower failure rates. Among the key applications are nanocoating of metallic surfaces to achieve super-hardening, low friction, and enhanced corrosion protection; "tailored" materials for infrastructure and vehicles; and "smart" materials that monitor and assess their own status and repair any defects resulting from fatigue, fire, etc.

- Nanotechnology has great potential to support advanced communications that maximize the benefits of intelligent transportation systems and obviate the need for some travel altogether; sensors that continually monitor the condition and performance of roads, bridges, and other infrastructure; and "brilliant" vehicles that can avoid crashes and improve operator performance.

- New materials developed through nanotechnology will permit the ultra-miniaturization of space systems and equipment, including the development of "smart," compact sensors; minuscule probes; and microspacecraft. Applications include economical supersonic aircraft; low-power, radiation-hardened computing systems for autonomous space vehicles; and advanced aircraft avionics.

---

[7] Rice University Department of Chemistry, ***Initiatives in Nanotechnology,*** Internet page http://pchem1.rice.edu/nanoinit.html; July 27, 1995

[8] Office of Legislative and Public Affairs, National Science Foundation; "Hearing Summary: Nanotechnology Hearing Confirms It's a Small World After All;" June 22, 1999

[9] Slightly adapted from Lacombe, Annalynn; " GRAND CHALLENGE: Application to Economical and Safe Transportation ," Attachment 2h to the draft Report of the National Science and Technology Council's Interagency Working Group on Nanotechnology.

- Nanotechnology has the potential to reduce transportation energy use and its impacts on the environment. Applications include nanosensors to monitor vehicle emissions and trigger traps for any pollutants observed; nanoparticle-reinforced materials that replace metallic components in cars; replacement of carbon black in tires with nanoparticles of inorganic clays and polymers, leading to tires that are environmentally friendly and wear-resistant; and carbon-based nanostructures that serve as "hydrogen supersponges" in vehicle fuel cells.

Breakthroughs in nanotechnology also should make possible quantum computers, which will exceed the limits on the speed and miniaturization of conventional computers by exploiting the quantum nature of reality. Conventional computing machines are limited by the manufacturing capability to create smaller and smaller circuits and chips, and to dissipate the heat which is generated as the device operates. Quantum computers offer a way around these obstacles.[10]

A Japanese team has already demonstrated a nanometer-scale superconducting qubit (quantum bit, the fundamental elements quantum computers use to work) chip. The device combines the properties of a quantum dot -- a box so small that adding an electron is a significant change -- with the quantum purity of the superconducting state, where electricity flows without resistance. At this stage, the qubit maintains its properties for only a very short time, up to about two nanoseconds. The next steps towards viable computers are to extend the limited lifetime of the qubits, and to connect qubits to make simple logic gates and circuits.[11]

Quantum computers should far exceed the speed and efficiency of conventional machines. They will handle computation with new algorithms (computational procedures or rules) based on quantum principles. Preliminary areas of application under discussion including factoring large numbers, searching of extremely large databases, and simulation of other quantum-mechanical systems. They may be used to design other nano-scale manufacturing and mechanical systems.[12]

Another possibility is the emergence of biocomputers, which would use DNA or other biological materials to encode numerical values and data, and use chemical reactions to generate outcomes. Techniques for synthesizing, reading, cutting and splicing, and classifying DNA sequences have already been developing in the context of research with recombinant DNA. Computers based on such

---

[10] Milburn Gerard; ***Schrodinger's Machines: The Quantum Technology Reshaping Everyday Life;*** W.H. Freeman and Company; ISBN 0-7167-3106-1, 1997

[11] "Qubit Chip: A superconducting chip suggests a practical path to medium-scale quantum computing," in ***Scientific American***, August 1999 Issue.

[12] "Subatomic Logic: Researchers nudge closer to the goal of quantum computing," in ***Scientific American,*** September 1996 Issue.

approaches theoretically could perform any calculation that any conventional computer could, operating on a "massively parallel" basis, with huge amounts of memory available, and with little energy consumption. Some experts view such molecular scale machines as longer-term options, and do not expect them to enter service in the near term.[13] However, a Hewlett-Packard team has already created a molecular-based logic gate – a basic building block of all computers – and are working on new processor production technologies, and chemical processors that might supersede today's silicon computer chips.[14]

In summary, breakthroughs in nanotechnology could make possible fabrication of materials at the molecular scale, self-repairing structures, totally new types of computers, and accelerated emergence of true intelligent systems. They are truly "wild cards" for system forecasts to consider.

Impacts of the New Technologies

Despite some pessimism about unanticipated impacts, the public's expectations about the impacts of technology are quite positive. Their concerns focus on a few key issues, including urban growth, environmental impacts, potential loss of privacy, etc. For example, the transportation enterprise is essential for economic growth, but currently accounts for approximately one third of the nation's fossil fuels use, and contributes about one third of the nation's greenhouse gases. Expanding data systems speed many transactions, but raise fears about the erosion of personal privacy. Nevertheless, there seems to be an abiding faith that responsible technological improvements, coupled with needed structural changes in the transportation system, will maintain and expand future mobility without compromising other key elements of America's quality of life.

---

[13] Delcher, Arthur; Hood, Lee; and Karp, Richard; ***Report on the DNA/Biomolecular Computing Workshop – June 6-7, 1996***; supported by the National ScienceFoundation, 1998.

[14] ________________, "Computing After Silicon," in ***Technology Review***, September/October 1999 issue.

THE CHALLENGES AND OPPORTUNITIES FOR TRANSPORTATION-2020

Worldwide, a number of forces are shaping the direction of transportation over the next two decades. Understanding these changes and opportunities is critical to achieving our nation's transportation goals (Appendix B suggests some goals for transportation in 2020 and beyond.) Key among these global changes are: shifts in demographics, accelerated economic growth and globalization, growing urbanization and motorization, increasing concerns for safety and security, changing technological trends in information and communications, and enabling technologies for sustainable transportation.

a. Changing Demographics

Two major demographic changes will influence the scope and character of world transportation demand in the 21st century: overall population growth and the aging population in the industrialized world. Over the next 25 years, world population is projected to grow from its present 5.5 billion to 8.5 billion people. By far, most of this growth will be in the cities of the developing world. The increased demand for transportation will require the expansion of existing infrastructure for all modes of transportation and perhaps deployment of new transportation alternatives.

At the same time, in the U.S. and many other developed countries, the lack of geographic and financial resources to build needed physical infrastructure will increase pressure for more efficient management and operation of existing systems, and alternatives to some kinds of travel. Information and telecommunication technologies provide a very attractive option for accomplishing this.[15] Related use of information networks for "virtual" business conduct may reduce demand for some kinds of personal travel, while simultaneously increasing demand for other kinds of passenger and freight services. Marine systems may become increasingly important in serving transportation demand in developed coastal areas where land for system expansion has become scarce. [16]

While industrialized countries' populations will stabilize and perhaps even decline, there will be further aging of these populations. Today, over 12 percent of the United States' and 14 percent of Europe's population is over 65. By 2020, over 20 percent of the population (about 53 million in the US) will belong to this group. In addition, the baby boomers currently constitute 28 percent of the U.S. population, but control more than 51 percent of the nation's wealth, some $2.6 trillion dollars. As the group ages, funds formerly devoted to buying homes, raising children, and paying for college will become available to these senior citizens, increasing their freedom for discretionary travel and tourism. This dramatic growth in the aging population will necessitate new approaches to transportation and

---

[15] *Cairncross, Frances;* ***The Death of Distance: How the Communications Revolution Will Change Our Lives***; Harvard Business School Press; ISBN 0-87584-806-0; 1997.

[16] *Japanese Ministry of Transport;* ***Development of New Transport Technology***; Internet Page at http://www.motnet.go.jp/info/develo.htm ; November 1997.

mobility, among them changes in traditional transit services, transportation infrastructure, recreational travel opportunities, and vehicles [17] Integrated communities, focusing on the needs of the elderly and having their own shopping, entertainment and service elements linked by specialized transit systems, already exist and may proliferate as more people retire over the next two decades.

b. Economic Growth and Globalization

Expanding economic growth throughout the world is providing a base for the development of newly emerging upper and middle income classes, demanding access and mobility. Gross domestic product per capita is steadily increasing in many countries. This trend is quite dramatic in newly industrialized countries, particularly in several Pacific Rim nations. More people have more disposable income than in any other period in human history. This income, combined with the influence of the mass media and telecommunications, will continue to create a booming travel and tourism market. As world tourism becomes an increasing share of transportation demand, the capacity of many nations' surface and air transportation infrastructures will be strained.

In parallel with growth in international tourism and travel will be corresponding increases in international goods movement. Low-cost communication and transportation networks have already resulted in a global manufacturing and marketing enterprise. There will be a continuing - if not expanding - pressure away from warehousing towards "just in time" deliveries of raw materials for use in manufacturing and deliveries of its completed products to the consumer. This will drive the freight transportation system to seek faster line haul performance, and more effective linking between shipment segments. The rise of electronic commerce will create a huge demand for small package delivery services as purchasing items over the Internet becomes commonplace. The burgeoning information infrastructure will simultaneously be a key resource supporting transportation, while simultaneously creating a variety of new demands for transportation services.

In this interdependent world economy, continued growth in international trade will increase the demand for freight transportation facilities. It will also place increasingly stringent cost and reliability requirements on transportation networks, particularly on intra-regional networks that link increasingly dispersed networks of interconnected businesses. Modeled on regional authorities (like the New York-New Jersey Port Authority and the Transcom partnership of today) multi-modal integrated planning, infrastructure investment and operations management will assure cost-effective regional economic development. Public-private ventures following these models should proliferate as the approach becomes more familiar.

---

[17] Wolf, Michael J.; ***The Entertainment Economy: How Mega-Media Forces are Transforming Our Lives***; Times Books, a division of Random House, Inc.; ISBN O-8129-3042-8; 1999.

c. Urbanization and Motorization

About 45 percent of the world population currently are urban dwellers. By 2025, more than 60 percent of the projected 8.5 billion people in the world will be living in cities -- many of them in mega-cities with populations of 10 million or more. Together with economic development, growth in the world's urban areas has led to a dramatic increase in the number of motor vehicles over the past 25 years. In 1970, there were 246 million vehicles registered in the world, 44 percent of them in the United States. By 1992, the world had 614 million vehicles, two and a half times the number in 1970, with only 31 percent in this country. In fact, the global fleet has been growing linearly since 1970, with each year bringing an additional 16 million vehicles. Should this trend continue, there would be more than 1.1 billion vehicles in the world fleet by 2025.

d. Safety and Security of the Global Transportation System

Over the next two decades, continued growth in world transportation demand will lead to heightened public and private concerns for transportation safety and security. For example, the growth in automobile use will bring with it a parallel potential for a dramatic increase in automobile-related deaths and injuries. This is particularly true for countries in the developing world, where the number of motor vehicles is growing far faster than the physical, legal, and institutional infrastructures needed to accommodate them. From 1968 to 1985, automobile fatalities increased by more than 300 percent in eight African countries and by almost 200 percent in six Asian nations. Even in the more industrialized countries, where safety records are typically good by historical standards, the private automobile will continue to present safety risks. The need for work on low cost crash avoidance and mitigation techniques for personal vehicles will remain for the foreseeable future.

Greater demand for air travel will place additional stress on an already heavily burdened aviation system. Countries will seek to accommodate air travel demand by moving toward "free flight" -- a system wherein aircraft operators have wide latitude for selecting flight paths, speeds, and altitudes that best satisfy their operational requirements. As a new global infrastructure for air traffic management emerges, questions will arise concerning the reliance on satellite and digital technologies, the increasing dependence on complex software-based aids and systems, and the need for global standards and interoperability guidelines. Moreover, the troubled state of the world and the attractiveness of aviation as a terrorist target make it likely that aviation security, as well as security in other modes of transportation, will be a major area of concern well into the 21st century.

e. The Digital World: An Information Technology and Telecommunications Revolution

In the past, changing transportation needs have typically been met through innovations in three areas: transportation vehicles; the physical infrastructure that supports their use; and the people who design, build, operate, and maintain the vehicles and infrastructure, and who plan and manage the transportation enterprise. More and more, the burgeoning demands on the transportation system will be met through a fourth means: the development of an information infrastructure supporting transportation's physical infrastructure.

Particularly important is a phenomenon experts call convergence: over the next few decades advances in computer, information, and communications technologies will come together in an integrated information infrastructure supporting all of society. In the home, information, entertainment, and access to electronic commerce will be consolidated in one set of input and display devices. Dramatic changes in the ways of organizing and managing transportation, trade, and work activities also become possible with the availability of "intelligent personal computer assistants,".[18]

There will be an increasing number of potential alternatives for various transportation functions, each offering its own benefits. Transportation vehicles manufactured 25 years hence should offer dramatic advances in sustainability, performance, and cost based on refinement and innovation affecting almost every component. Vehicles themselves will be customized and built to personal capabilities, needs and preferences. Advanced computer-based tools will enable concurrent design, testing and manufacture of vehicles, dramatically shrinking time and cost to market. In fact, one component of any strategy to meet transportation needs will be to stimulate development of a range of alternatives to some physical travel.

The wide availability of highly accurate radionavigation services will also be a major force transforming transportation and society at large. The first edition of the ***Federal Radionavigation Plan*** in 1980 only referred to radionavigation applications for mariners, aviators, space navigation, and the military. Less than two decades later, radionavigation systems have become a true public utility, and are used in virtually every area of transportation, and in many other sectors of the economy. Such systems are used on automobiles, trucks, buses, trolleys, passenger and freight trains, police cars, fire trucks, and ambulances, as well as by farmers, miners, surveyors, pleasure boaters, hikers, fishermen, and explorers. The timing elements of radionavigation systems are used by the telecommunications and electric power industries which, in turn, support every part of society and the economy. These trends will continue and accelerate with proliferation of public and private sector differential GPS services, and small, low-priced GPS receivers for personal use.

Real-time information on transportation choices and traffic conditions will lead to short-term changes in travel patterns. More workers can conduct business at home or from locations other than their office, including their car or on other modes of transportation. In real time, Americans are already "plugged in" and assisted by personal computing technology at home and work. We are witnessing a steep rise

---

[18] *Worzel, Richard;* ***The Next Twenty Years of Your Life: A Personal Guide into the Year 2017***; Stoddard Publishing Company; ISBN 0-7737-3013-3; 1997 .

in use of the Internet, and growth in paging and other mobile communications services which permit easy access to the vast array of available electronic information. Although physical mobility will continue to be a prerequisite for many jobs, services, and leisure activities, effects associated with telecommunications advances could stimulate travel and transportation demand. Information technology will, therefore, play a prominent role both in shaping future transportation demands, and in enabling advanced management and operations to meet those demands in an era of constrained expansion of physical infrastructure.

f. Transportation Sustainability Enabled by Technology

Along with the world's growing reliance on motor vehicles has come a concomitant increase in environmental and energy impacts -- global carbon emissions, petroleum consumption, air pollution, and congestion. Coupled with high population growth rates and a growing vehicle fleet, sprawling urban development is a major cause of pollution, congestion, and poverty in many of the world's cities.

These patterns of sprawl have profound implications. Employees who both work and live in low density places have scattered travel patterns -- they do not travel along highly concentrated corridors, and they have few alternatives to the private car when they travel. Conventional transit operations cannot serve low density areas economically. Employees who live in the core of metropolitan areas but work in the suburbs (reverse commuters) also may have limited travel options. Overall, these population and land use trends accelerate the travel patterns linked to the growth of a service-based economy, leading to longer work and non-work trips, more scattered origins and destinations, and greater dependence on single-occupancy private vehicles.

The Partnership for a New Generation of Vehicles (PNGV) program will yield significant improvements for all motor vehicle types, such as lighter weight, lower cost materials; improved emission characteristics; and greatly lessened petroleum requirements in future personal vehicles. In general, technological advances will be critical factors in ensuring that the overall transportation system is brought to its full potential in terms of life-cycle economics, energy efficiency, and minimal adverse societal impacts. Programs for medium sized and heavy duty vehicles will yield similar benefits.

The digital highway and fiber optic communications, and the advent of personal communication systems promise to replace significant parts of today's physical transportation traffic and further increase the global reach, speed, and productivity of information-assisted and -enabled transportation.

TRANSPORTATION OPTIONS AND OPPORTUNITIES FOR 2020 AND BEYOND

General System Characteristics - The Department is committed to evolving a 21st century transportation system that is international in scope, intermodal in form, intelligent in character and inclusive in service. Individual modal improvements and more sophisticated integration of modal elements will bring about this system.

Human-Centered Transportation Design - The combination of better understanding of human factors with an increasing sophistication in system design approaches will lead to proliferation of "human-centered" transportation systems. Such systems are constructed "from the inside out," and are driven by the capabilities, preferences and limitations of the users. For example, vehicles for the elderly will be able to compensate in part for their slowed reaction time and reduced visual acuity with sensors, intelligent systems, "heads up" and other display technologies, and night vision hardware. Detecting and instituting countermeasures for fatigue and other performance degradations will be commonplace.

The Evolving Personal Vehicle - Despite some major advances in other modes, the passenger automobile probably will continue to dominate transportation in the United States. However, the passenger car will go through some marked changes over the next 20-30 years. More fuel-efficient gasoline powered cars will be joined by hybrid diesel-electric vehicles, alternatively-fueled vehicles, and fuel cell powered vehicles. The market for automobiles may partition, based on trip lengths and purposes. Electric cars and station cars, powered by advanced or conventional electric batteries, as well as solar-powered and people-powered personal vehicles will assist commuters to perform local errands or economically reach transit system suburban collection terminals. These will complement larger vehicles which will be used for longer trips, or when additional carrying capacity is needed. Both kinds of vehicles should be lighter and safer than current autos, as vehicle structures use more new plastics and composite materials.

Application of improved understanding of human performance and behavior, vehicle crashworthiness, and biomechanics coupled with the structural improvements noted above, will help substantially to mitigate crash impacts. However, most of the systems to improve safety will be introduced as equipment on new vehicles. The integration of new systems on a fleet wide basis may take 10 to 20 years from initial introduction of the technology. The average age of vehicles in the fleet is increasing, as more solid construction and reduced needs for maintenance permit consumers to retain their vehicles longer. Overall safety statistics will improve, but may not fully reflect the benefits of new crash avoidance/mitigation techniques at once.

Intelligent Vehicle Infrastructure - Today's cluster of intelligent transportation vehicles and travel planning and information services will be integrated in new vehicles with smart driver/operator technologies; in-car sensors; on-board emission management systems; and links to the wayside information infrastructure. This will enable efficient, safer, and more environmentally benign ground transportation in 2020 and beyond. Advanced multi-spectral sensors, distributed microprocessors, communications, tracking technologies and display of traffic information in urban traffic management centers will enable more efficient use of limited infrastructure capacity, relieve congestion and lessen the environmental impacts of transportation.

Personal commuting and family pleasure travel will have many more real-time travel planning, scheduling and routing options, thanks to intelligent recreational vehicles, advanced public transportation systems, and automated highway systems. The safety of personal travel and of commercial vehicle operations will be assured by advanced incident management, and onboard collision avoidance radars and intelligent cruise control. Speech recognition software will allow drivers to adjust vehicle controls simply by asking for the change. In-car navigation and information systems will be commonplace, integrated directly into the vehicle's electronics: maps, weather data, traffic conditions, and alternative routes will be immediately available. Night viewing infrared detectors will enhance driving safety at all times and in all weather, and small video cameras may substitute for items like rear view mirrors. Intelligent driver trainers and simulators will be used to prepare and test for driver licensing and for sobriety testing of drivers, as well as for safety recertification.

For intercity trips, there should also be fully automated highways allowing high-speed auto travel with minimal driver intervention on selected routes. These may be separate highways, or lanes on existing/expanded highways reserved for vehicles with the appropriate high-speed control packages. The intelligent infrastructure for these highways will be compatible with, and possibly integrated into, multimodal traffic control systems directing aviation and maritime movements.

Telecommuting, Teleconferencing and Real-Time Traveler Information - Home-based employees and corporate telecommuters – linked by global networks and logged into "virtual offices"-- should be routine work concepts in 2020. Virtual reality and telepresence applications will be common, and available worldwide, significantly reducing the need for daily commutes to work in some occupations, and enhancing productivity and safety. Video-telephony, satellite-based video, and data communications networks will reduce the need for business travel by a substantial fraction of skilled workers. Home and personal vehicles, trains, planes, and buses will have broad-band communications, computer, video-telephony, and message display ports -- compatible with personal palm-size or smaller units -- to enable real-time travel planning, scheduling and reservations, and access to offices anywhere in the world. This will relieve congestion on highways and roadways, which are now free to accommodate new priority and recreational vehicular traffic.

Urban and Community Public Transportation - Public transportation systems will provide widely available, inexpensive alternatives to the personal vehicle for shorter trips. The recent emphasis on "smart growth" and "livable communities" will promote new human-scale developments which are designed from the start to be served by local circulation and transit systems. Shuttle services will link these complexes with intercity modes for longer trips among clusters of development.

Some low speed, shorter range maglev systems will be integrated into structures, functioning as horizontal elevators among the buildings in employment, sales, and entertainment complexes. There may also be application of such maglev systems as line haul modes in selected urban corridors. Low cost fiber reinforced composite elevated guideways will enable widespread deployment of both maglev and wheeled people movers to link airports, vertiports, and multimodal terminals with the center city and suburban activity centers.

Computer dispatched para-transit vehicles serving the suburbs and elderly and disabled passengers will integrate with, and share HOV lanes with, advanced technology urban and intercity transit buses in more densely developed areas. Specialized and public transit services will reach into rural and lower-density areas, linking their carless residents to urban services. Many of these options will be powered using alternative fuels or use fuel cells.

The transit systems will profit from the technologies of the intelligent transportation infrastructure, with safety and performance improvements in bus vehicle maneuvering, merge collision avoidance, forward collision avoidance, and docking. Automatic vehicle location systems will be commonplace, with positions monitored from metropolitan scale traffic management centers. Real-time information on actual bus positions and schedules should be readily available to potential riders. With an increasing number of elderly people as riders, these systems will exemplify the "human centered design" concept.

High-Speed Ground Transportation - High-speed ground transportation systems for intercity passengers and high value freight will be in place in a number of different corridors in a variety of forms. Systems entirely separate from conventional railroads will serve the Northeast Corridor and the San Diego-Los Angeles-San Francisco Corridor using either 200 mph railroad or 300 mph maglev technology. Similar lines will be under construction in some less highly populated corridors but most of these will continue to be served by more conventional services offering 100 to 150 mph maximum speeds on upgraded partially grade separated tracks which also accommodate freight trains. Many large metroplexes will also have high speed, 100+ mph, commuter service on a track partly shared with intercity trains.

Intra-regional freight distribution networks - The freight transportation system of 2020 will be a tightly connected network, allowing shippers to tailor their choice of transportation services to the specific freight items to be shipped, their sizes, their priority for delivery, and their destinations. Current priority air cargo services already interface with multimodal freight transportation networks, enabled by people who assist automatic sorting and routing, using "just-in-time" logistics and electronic data interchange (EDI) information traffic. This may serve as a model for other applications.

The coverage of ground (rail and highway), air, and sea networks of transportation infrastructure will continue to expand. Information technology could lead to a fully multimodal "smart" freight control and tracking system, and a rapid ground based distribution system could further expand its reach. Electronic tags will facilitate locating and tracking cargo containers and vehicles in transit, with the information combined with electronic bills of lading and automated handling, sorting, and routing at intermodal terminals. Global in-transit visibility using ground and space-based communications routinely will be used to follow transportation of bulk, parcel, and high value cargo. Fleet management systems for freight vehicles will provide unprecedented flexibility in locating and projecting the arrival times of key shipments. Automation and robotics will enable operation of high productivity intermodal terminals and logistics chains, to sustain just-in-time materials and products delivery and "lean production" agile manufacturing for industry and trade. Future cars, boats and aircraft will even be customized to order, manufactured, and rapidly delivered.

The expansion of Pacific Basin trade will create demand for faster and higher capacity ships and air cargo freighters. In some urban areas, delivery might be expedited with a network of soft-tunneled underground cargo tubes, coexisting with gas, sewer, electric, telecommunications, and water pipeline infrastructure. Compressed air or liquid carbon dioxide slurries might be used to rapidly convey cargo from some source suppliers to users' destinations. Special-purpose response units and their vehicles will be pre-positioned to deal with accidents, pollution incidents, and natural disasters impacting transportation, their operations linked through shared control and communication systems.

Next Generation Ferries and Marine Transportation - Ferry services will become more prevalent, to compensate for reduced land available in highly developed areas,. High speed hydrofoils, catamarans, SWATH (small water area twin-hull) ships and hovercraft will operate as high speed ferries in the coastal mega-plexes that will have evolved from today's east and west coast urban complexes.

Intelligent vessel traffic services, coupled with differential GPS navigation, electronic charts and related vessel improvements, will greatly improve the safety and efficiency of the marine transportation system. Marine security information will be readily available to vessel operators, integrated into the displays of data from which control decisions are made. Ocean-going vessels will be responsible for a large proportion of international movement of bulk commodities, but intelligent control technologies, improved weather forecasting, and higher vessel speeds will have increased the safety of these operations while also improving their productivity. As required by the Oil Pollution Act of 1990, only double-hulled oil tankers will be in service in U.S. waters.[19]

The growth of global tourism will lead to more cruise ships of all sizes, linked to planes and trains through multimodal port terminals. These vessels will carry international and U.S. vacationers across the oceans and along major inland waterways. Some forecast particular growth in very large ocean liners, carrying several thousand passengers. Advanced super-high

[19] Also see U.S. Department of Transportation; ***An Assessment of the U.S. Marine Transportation System: A Report to Congress***; Washington, D.C.; September 1999; especially Pages 63-70.

speed "techno-superliners" – the next generation 50-100 knot passenger ships – will be operating both as long distance coastal and ocean-crossing carriers. These vessel technologies, applied to tomorrow's container ships, tankers and bulk carriers, will help deal with greatly increased world trade volume by improving the speed of delivery for water cargo. Mega-float offshore airports and intermodal terminal-ports will be coupled with high speed sea-ferries to expand air traffic airport capacity and better serve the U.S. and world coastal metro-plex hubs. Larger and larger cruise ships may evolve into self-propelled floating resort "cities," which can migrate based on changing weather and climate conditions.

Future Aircraft and Traffic Control Concepts - A new generation of advanced aircraft, using lighter and stronger materials and new propulsion concepts will replace today's aging commercial and general aviation air fleet. They will take advantage of an enhanced navigation, communication and surveillance air traffic control system now being deployed. The emerging systems will rely on the next generation global positioning satellites for navigation, and on dedicated, secure aviation air-to-air and air-to-ground space-enabled communication networks to assure safe operations. Aviation security measures will be simultaneously more effective and less obtrusive, thanks to advances in sensor technology.

Travelers may make expanded use of small aircraft and small airports for business and personal intercity transportation, especially in lower density areas. NASA is working on the Small Aircraft Transportation System (SATS) initiative, which is intended to provide by 2022 a system that will enable doorstep-to-destination travel at four times the speed of highways to 90% of Nation's suburban, rural, and remote communities. It includes expanding the number of public-use airports that are equipped for near all-weather operational support of SATS aircraft. SATS aircraft will encompass new avionics, airframe, engine, and pilot training technologies. These new technologies will create new features and capabilities that will significantly improve affordability, safety, and ease of use over today's aircraft.

The next generation of commercial aircraft will be safer, quieter, and environmentally compatible, as well as more efficient and customized to market niches: low fare, business, tourist, etc. Super-jumbo, wide-body jets may carry 800 passengers on routes serving the Pacific basin or major shuttle corridors, relieving air traffic congestion yet accommodating growing global tourism demand. Such large airliners will be cleaner, quieter, and more fuel-efficient, but will also bring added challenges in security, baggage handling, and traffic management around airports they operate from.

Airport complexes (Reagan National, Washington Dulles, and Baltimore-Washington International; Newark, NY La Guardia, NY JFK International, and Islip/Mac Arthur; Manchester NH, Boston MA, and Providence, RI) serving heavily developed areas should continue to proliferate, with associated ground access problems as traffic levels rise. Inter-airport ground shuttles, maglev systems, short-range air links, and better integrated intercity services may be used to lessen these pressures. These multi-modal linkages, combined with improved weather forecasting and user-oriented ticketing systems, may reduce overall travel delays, and provide alternatives for travelers whose journeys are interrupted by adverse flight conditions.

Environmentally friendly supersonic and hypersonic aircraft with advanced noise and sonic boom reduction technologies will transport passengers and high value cargo faster. Tiltrotors, quiet helicopters, and other vertical take-off and landing (VTOL) agile small and light aircraft will rapidly carry and deliver intercity business travelers to the downtown, to reliever airports, or to suburban destinations, replacing some corporate jets. These aircraft will incorporate "fly-by-light" technology and artificial cockpit vision (which fuses radar, infrared imaging and video) for all-weather, 3-D situational awareness and the safety that comes with it.

Low-cost Access to Space - Low-cost, user-friendly commercial space access is the key to the future of global telecommunications, safe navigation for all types of transportation vehicles, and operations of both civil and military transportation services. Current activities made possible by orbital platforms will become more inexpensive and expand: massive transmissions of voice communications and data will occur in real time, monitoring of changing weather and other conditions at the surface of the earth will improve; positioning and navigation services will become more accessible; and fleet management and parcel tracking will be facilitated. Commercial exploitation of space will continue with expanding telecommunications, new remote sensing applications, medical complexes taking advantage of the zero-gravity environment, and manufacturing and materials processing complexes in orbit. There may be the first signs of a premium fare space travel and tourism industry. The presence of a permanent space station or lunar base should accelerate these trends.

Manned traffic into low earth orbits should increase substantially. The X-33/Venture Star and X-34 should lead to single-stage-to-orbit shuttles which carry payloads directly into space, return to earth, and then are quickly recycled for their next mission. Low-cost, versatile launch vehicles, associated spaceports, and payload integration infrastructure will make the continued growth possible. Currently in testing are commercial launch vehicles with controlled re-entry characteristics to allow their re-use, and air-launched orbital vehicles which function as air-breathing space planes. In addition to orbital missions, these new classes of aerospace vehicles operating sub-orbitally could provide access to anywhere in the world in less than two hours to transport premium-fare passengers and high-priority freight. Just as with more conventional air services, the space-oriented operations will have to be integrated into the operations of the transportation system as a whole.

The Hydrogen Economy - Several kinds of fuel cells, which produce electricity from combining hydrogen with oxygen, are now in development and testing on advanced transit buses, train locomotives, and ships. The four principal types under investigation at present are molten carbonate, phosphoric acid, proton exchange membrane (PEM), and solid oxide fuel cells. These technologies may lead to a future hydrogen-based fuel economy.

Governments and industries are in a worldwide race to create a hydrogen economy for electric power generation, in the near term reforming fuels to release hydrogen for use in homes and manufacturing plants or onboard transportation vehicles. (Breakthroughs in fusion energy and/or the development of a lunar base or similar source for the Helium 3 used in fusion might accelerate this trend.) Ultimately, hydrogen may be the sustainable energy source of the 21st century, and eliminate greenhouse gas generation by transportation vehicles. Until then, technology advances, coupled with volume-based price reduction, promise to make fuel cells the choice for future personal vehicles.

Transportation Planning and Decision-making - As our understanding of transportation's contribution to economic growth, the planning process for future systems should become more sophisticated, reflecting advances in economics, policy assessment, risk evaluation, and understanding of political systems. Building on tools like today's TRansportation ANalysis SIMulation System (TRANSIMS)[20] model, advanced simulation techniques will enable decision-makers to investigate the impacts of their transportation choices on other sectors. Advanced display techniques will portray these activities, facilitating communication of impacts occurring and why choices were made. In addition, the development of personal and electronic networks among elected officials, transportation professionals, and other professional communities will enable sharing of experiences, and foster broader implementation of productive innovations.

SUMMARY

The transportation system of 2020 will be global in scale, and more technically advanced. It will have to accommodate many more users of varying abilities and needs. It will have to be safer, accessible, faster and cleaner. It will have to be much more dynamic and flexible, adapting to its wide variety of users quickly and efficiently. Advanced research and innovative technologies can contribute to making this vision of transportation a reality.

---

[20] Morrison, Jack and Loose, Verne; ***TRANSIMS Model Design Criteria as Derived from Federal Legislation***; Los Alamos National Laboratory for U.S. Department of Transportation; U.S. Environmental Protection Agency; and U.S. Department of Energy, Washington, D.C. June 1995

REFERENCES AND BIBLIOGRAPHY

1. -----------------; "Computing After Silicon;" in ***Technology Review;*** September/October 1999.

2. -----------------; "Qubit Chip: A superconducting chip suggests a practical path to medium-scale quantum computing;" in ***Scientific American;*** August 1999.

3. -----------------; "Subatomic Logic: Researchers nudge closer to the goal of quantum computing;" in ***Scientific American;*** September 1996.

4. Bretz, Elizabeth A.; "Technology 1999 Analysis and Forecast: Transportation;" in ***IEEE Spectrum;*** January 1999; Pages 98-103.

5. Burris, Daniel with Gittines, Roger; ***Technotrends: How to Use Technology to Go Beyond Your Competition;*** Harper Business; ISBN 0-88730-627-6; 1994.

6. Cairncross, Frances; ***The Death of Distance: How the Communications Revolution Will Change Our Lives***; Harvard Business School Press; ISBN 0-87584-806-0; 1997.

7. Cetron, Marvin and Davies, Owen; ***Probable Tomorrows: How Science and Technology Will Transform our Lives in the Next Twenty Years***; St. Martin's Press; ISBN 0-31215-429-1; June 1997.

8. Coates, Joseph; Mahaffie, John; and Hines, Andy; ***2025: Scenarios of U.S. and Global Society Reshaped by Science and Technology***; Oakhill Press; ISBN 1-886939-09-8; February 1997.

9. Delcher, Arthur; Hood, Lee; and Karp, Richard; ***Report on the DNA/Biomolecular Computing Workshop – June 6-7, 1996***; supported by the National Science Foundation, 1998.

10. Gershenfeld, Neil; ***When Things Start to Think;*** Henry Holt and Company; ISBN 0-8050-5874-5; 1999.

11. Gleick, James; ***Faster: The Acceleration of Just About Everything***; Random House, Inc.; ISBN 0-679-40837-1, 1999.

12. Halal, William; Kull, Michael; and Leffman, Ann; "Emerging Technologies: What's Ahead for 2001-2030," in ***The Futurist;*** November-December 1997.

13. Harman, Willis; ***Global Mind Change***; Berrett-Koehler Publishers; ISBN 1-57675-029-9; 1998.

14. Hogan, James P.; ***Mind Matters: Exploring the World of Artificial Intelligence***; The Ballantine Publishing Group; ISBN 0-345-41240-0; March 1998.

15. Japanese Ministry of Transport; ***Development of New Transport Technology***; Internet Page at http://www.motnet.go.jp/info/develo.htm; November 1997.

16. Kaku, Michio; ***Visions: How Science will Revolutionize the 21st Century***; Bantam Books; ISBN 0-38548-499-2; September 1998.

17. Lacombe, Annalynn; " GRAND CHALLENGE: Application to Economical and Safe Transportation," Attachment 2h to the draft Report of the National Science and Technology Council's Interagency Working Group on Nanotechnology; Volpe National Transportation Systems Center; Cambridge, MA; 1999.

18. Middleton, Bob; ***The High Speed/Automated Transportation Home Page;*** Internet Page at http://eb-p5.eb.uah.edu/maglev/maglev.html; February 1996.

19 Milburn Gerard; ***Schrodinger's Machines: The Quantum Technology Reshaping Everyday Life;*** W.H. Freeman and Company; ISBN 0-7167-3106-1, 1997

20. Morrison, Jack and Loose, Verne; ***TRANSIMS Model Design Criteria as Derived from Federal Legislation***; U.S. Department of Energy, Los Alamos National Laboratory for U.S. Department of Transportation, U.S. Environmental Protection Agency, and U.S. Department of Energy; Washington, D.C.; June 1995.

21. National Aeronautics and Space Administration; ***Aeronautics and Space Transportation Technology: Three Pillars for Success;*** Washington, D.C.; March 1997.

22. National Science and Technology Council; ***NSTC Transportation Science and Technology Strategy;*** Washington, D.C.; September 1997.

23. National Science and Technology Council; ***NSTC Transportation Strategic Research Plan,*** Washington, D.C.; May 1999.

24. National Science and Technology Council; ***NSTC Transportation Technology Plan***; Washington D.C.; November 1998.

25. Office of Legislative and Public Affairs, National Science Foundation; "Hearing Summary: Nanotechnology Hearing Confirms It's a Small World After All;" June 22, 1999

26. Petersen, John; ***The Road to 2012: Looking Toward the Next Two Decades;*** DOT-T-93-35; Washington, D.C.; March 1993.

27. Petersen John; ***Out of the Blue: Wildcards and Other Big Future Surprises***; The Arlington Institute; ISBN 0-96590-272-2; July 1997.

28. Rice University Department of Chemistry, ***Initiatives in Nanotechnology,*** Internet page http://pchem1.rice.edu/nanoinit.html; July 27, 1995

29. Sarewitz, Daniel; ***Frontiers of Illusion: Science, Technology and the Politics of Progress***; Temple University Press; ISBN 1-56639-415-5; 1996.

30. Taylor, Chris; "Dream Machines" in ***TIME Digital: Your Guide to Personal Technology***; New York, NY; March 8, 1999.

31. U.S. Coast Guard; ***Coast Guard 2020: Ready Today...Preparing for Tomorrow***; Washington, D.C.; May 1998.

32. U.S. Department of Transportation; ***An Assessment of the U.S. Marine Transportation System: A Report to Congress***; Washing D.C.; September 1999.

33. U.S. Department of Transportation; ***U Department of Transportation's Research and Development Plan***; Washington, D.C.; M 999.

33. U.S. Department of Transportation; ***Strategic Plan 1997-2002***; Washington, D.C.; September 30, 1997.

34. Verne, Jules; ***Paris in the Twentieth Century***; Random House; ISBN 0-679-44434-3; Translation copyrighted 1996.

35. Volpe National Transportation Systems Center, ***The Spirit of Innovation in Transportation Conference (Preprint Papers),*** Cambridge, MA; June 23-24, 1999.

36. Volpe National Transportation Systems Center; ***Symposium on Challenges and Opportunities for Global Transportation in the 21st Century***; Cambridge, MA; October 1995.

37. Wolf, Michael J.; ***The Entertainment Economy: How Mega-Media Forces are Transforming Our Lives***; Random House, Inc.; ISBN O-8129-3042-8; 1999.

38. Worzel, Richard; ***The Next Twenty Years of Your Life: A Personal Guide into the Year 2017***; Stoddard Publishing Company; ISBN 0-7737-3013-3; 1997.

Appendix A

GEORGE WASHINGTON UNIVERSITY
FORECAST OF EMERGING TECHNOLOGIES[21]

The following are projections of when key technologies will become available over the next thirty years. They have resulted from a Delphi survey of technical experts conducted by The George Washington University in 1990, 1992, 1994, and 1996. Key developments are summarized below grouped by their period of emergence, and probability of achievement [in brackets] as seen by the panel:

2000-2004

INFOTECH:	Entertainment on-demand [84] Videoconferencing [83]

2005-2009

TRANSPORTATION:	Hybrid vehicles common [69]
INFOTECH:	PC "convergence" [84] Advanced data storage [75] Standard digital protocols [70] Distance learning [78] Computer sensory recognition [73] Personal digital assistants [75] Information superhighway [78] Intelligent agents [79] Broadband networks [70]

2010-2014

TRANSPORTATION:	Electric vehicles common [70]
INFOTECH:	Expert systems [72] Machine learning [67] Computer language translation [65] Optical computers [64]
MATERIALS:	Buckyballs/buckytubes [59] Half of autos recyclable [58] Ceramics for engines [58]

---

[21] Developed from information in the article *"Emerging Technologies: What's Ahead for 2001-2030,"* by William Halal, Michael Kull, and Ann Leffman in the November-December 1997 issues of ***The Futurist***

2015-2019

TRANSPORTATION:	Fuel-cell electric cars [58] Intelligent transportation systems [58] High-speed maglev [58] Automated highways [58]
ENERGY:	Energy efficiency [61] Fuel cells [53]
INFOTECH:	Neural networks [61] Nanotechnology applications [66] Sophisticated robots [64] Biochips [54] Telecommuting [56]
MATERIALS:	Superconducting materials [56] Material composites [53]

2020-2024

TRANSPORTATION:	Clustered communities [53] Personal rapid transit [43]

2025-2029

TRANSPORTATION:	Hypersonic air travel [48]
ENERGY:	Fusion power [50]
MATERIALS:	Intelligent materials [57] Self-assembling materials [56]

TRANSPORTATION GOALS FOR 2020 AND BEYOND

Today's panoply of advanced technologies and innovative concepts provide only a glimpse of those that will be available in transportation in the year 2020. The challenge today is to foster enabling research activities that will provide the transportation breakthroughs of the next century, and then to demonstrate and deploy the advanced technologies and concepts to provide the American public with the world's best transportation system in the 21st century.[22]

This will require sustained investment of energy, imagination, and public and private resources as well as political commitment and leadership. It will require an environment that fosters innovative private-public solutions to the nation's transportation challenges, drives national transportation research and development investment strategies, and propels the nation towards a technology-enabled sustainable transportation system in the near term. Last, it will require a well-educated and informed population which not only will create the transportation system of the next century, but also will be able to use all of its capabilities. Some illustrations of the contributions that implementation of advanced technology and innovative concepts might make in achieving the nation's transportation goals follow.

GOAL: Safety
Reduce transportation-related deaths, injuries and property loss

- Reduce fatality and injury rates by 10% within 10 years and by 25% by the year 2020.

- Reduce property loss rate by 25% within 10 years and 50% by the year 2020.

GOAL: Mobility
Meet America's transportation needs by ensuring a seamless, accessible system that is efficient and effective while enabling maximum flexibility of user choices.

- Provide access to transportation services for all Americans within 10 years.

- Reduce the time and cost for access to the transportation system by 25% within 10 years and 50% by the year 2020.

- Increase private and public-sector access to information on transportation-related services and activities by a factor of 10 within 5 years and to all Americans by the year 2020.

- Increase passenger throughput by 50% in 10 years and 100% by the year 2020.

GOAL: Economic Growth and Trade

---

[22] *National Science and Technology Council;* ***NSTC Transportation Science and Technology Strategy;*** Washington, D.C.; September 1997.

Promote America's economic growth and competitiveness domestically and internationally through efficient and flexible transportation.

- o Double the dollar value of transportation-related exports (e.g., vehicles, systems, and technologies) within 10 years and triple it by the year 2020.

- o Reduce the cost to transport goods and freight by at least 25% within 10 years and 50% by the year 2020.

- o Reduce the time to transport goods and freight with other nations by 25% within 10 years and 50% by the year 2020.

- o While improving safety, double the transportation system throughput, in all weather conditions, within 10 years and triple it by the year 2020.

GOAL: Human and Natural Environment
Protect/ enhance the natural environment and communities affected by transportation.

- o Reduce emissions (e.g., CO_2) in new vehicles by a factor of 10 within 10 years and eliminate them by 2020.

- o Reduce the noise impacts of future transportation systems (e.g., vehicles) by a factor of two from today's systems with 10 years and by a factor of four by the year 2020.

GOAL: Security
Protect the nation by ensuring that the transportation system is secure and available for defense mobility and that our borders are safe from illegal intrusion.

- o Decrease delays in transportation service due to natural disasters, terrorism, system failures or other causes by a factor of 5 within 10 years and by a factor of 10 by the year 2020.

- o Decrease the number of security incidents/intrusions into the transportation system by 25% within 10 years and 50% by the year 2020.

- o Reduce drug smuggling and the entry of illegal aliens into the United States by a factor of 10 by the year 2020.

CORPORATE MANAGEMENT STRATEGIES:

- o Lower the real cost (e.g., time, resources) of maintaining the nation's transportation infrastructure by a factor of 2 within 10 years and by a factor of 5 by the year 2020.

- Increase national (i.e., private sector, academic, and government) investments in research on innovative transportation technologies and concepts for the 21st century by a factor of 3 within 10 years and by a factor of 5 by the year 2020.

- Decrease the time and cost required to apply innovative technologies and concepts to transportation-related products, systems, and services by a factor of 2 in 10 years and by a factor of 5 by the year 2020.

- Double the scientific and technical literacy of the American people concerning transportation-related systems, services, and technologies within 10 years and triple it by the year 2020.

- Double the percentage of the population that can pursue careers in transportation-related industries and careers within 5 years and triple it by the year 2020.

ion, L.